SPECIFICATION

TITLE

"METHOD FOR SLICE POSITION PLANNING OF TOMOGRAPHIC MEASUREMENTS, USING STATISTICAL IMAGES"

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is directed to a method for slice position planning of tomographic (magnetic resonance) measurements, including a protocol for operating a magnetic resonance imaging apparatus.

Description of the Prior Art

Magnetic resonance imaging (MRI, also known as magnetic resonance tomography (MRT)) is based on the physical phenomenon of nuclear magnetic resonance and has been successfully utilized as an imaging modality in medicine and in biophysics for more than fifteen years. In this imaging modality, a subject, such as a living patient, is subjected to a strong, constant magnetic field. As a result, the nuclear spins of the atoms in the subject, that were previously irregularly oriented, are aligned. Radio-frequency energy emitted into the subject then excites these "ordered" nuclear spins to a specific resonance. This resonance generates the actual measurement signal, which is received with suitable reception coils. By utilizing non-uniform magnetic fields (gradient fields) generated by gradient coils, the signals received from the examination subject can be spatially encoded in all three spatial directions. A slice of the examination subject for which an image is to be generated can be freely selected, thereby allowing tomograms of the human body to be obtained in all orientations. Magnetic resonance imaging as a tomographic method for medical diagnostic purposes is primarily distinguished as a "non-invasive" examination technique with versatile contrast capability. Due to the excellent

presentation of soft tissue, magnetic resonance imaging has developed into an imaging modality that is often superior to x-ray computed tomography (CT). Magnetic resonance imaging is currently based on the use of spin echo sequences and gradient echo sequences that enable an excellent image quality to be obtained, with measurement times on the order of magnitude of minutes.

Each examination (scan) of a subject in a particular magnetic resonance imaging installation must be planned in advance. The planning involves selection of the type of pulse sequence, as well as the selection or designation of many individual parameters of the selected pulse sequence. The selection of the pulse sequence and the parameterization thereof are, in turn, based on many variables that differ from scan-to-scan. Such variables are related to the specific patient, the type of imaging installation, and the particular type and orientation of the magnetic resonance image that is desired to be obtained. The image to be obtained is dependent not only on anatomical factors, but also on the particular pathological condition, or suspected pathological condition, that is being investigated.

For clinical MR scanners, protocols are predefined with regard to slice positioning, but such protocols are not based on the actual positioning of the patient in the scanner for the particular examination to be undertaken. Usually, the protocols are defined relative to the center of the origin of the basic field magnet, which usually also is the origin of the imaging volume, and straightforward axial, sagittal or coronal slices are selected depending on the preferred protocol orientation. ~~One~~ For performing the actual scan, the final slice position must be adjusted manually, otherwise the slice will not coincide with the desired body region of the subject. In principle, this manual procedure must be performed with regard to every protocol and every patient. This not only prolongs the time that the patient must

spend in the scanner, which is discomforting to the patient, but also slows the patient throughput (i.e., results in a smaller number of patients being scanned within a given time than would be possible without such manual positioning).

Conventionally, such manual re-alignment of the slices for the actual scan, compared to the slice alignment in the predefined protocol requires the use of a so-called localizer protocol. This involves positioning the patient in the scanner, undertaking a localizer scan, position the slices for the actual diagnostic scan based on the images obtained in the localizer scan, and undertaking the clinical or diagnostic scan from which diagnostic images will be obtained.

In the context of conventional slice position planning, the use of templates is described in United States Patent No. 6,195,409, and the processing of medical images employing techniques suitable for slice position planning is described in PCT Application WO 02/43003. The mapping of a particular property in the context of image processing is disclosed in PCT Application WO 02/098292, and the registration of object views is described in PCT Application WO 01/59708.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for slice position planning of tomographic measurements which avoids the above-described manual slice re-alignment. A further object of the present invention is to provide such a method which avoids the need for a localizer protocol of the type described above. This object is achieved in accordance with the principles of the present invention in a method for slice position planning of MR measurements wherein, instead of planning the slices for each individual patient for each individual scan, the slice or slices for a particular scan is/are planned using a statistical dataset which represents the geometrical details of the organ of interest in the scan. The statistical dataset

represents a "standard" image of the organ of interest. The dataset can be obtained from a standard organ atlas, many of which are known and accessible, or can be produced from a data acquisition system by averaging several measured datasets that have previously been obtained from other patients, and that have been stored. The statistical dataset, or atlas, is displayed as a planning representation in a global slice-positioning environment. The measurement for an imaging area (geometrical parameters, sequence parameters, etc.) is planned using this statistical dataset, and is stored as a standard measurement protocol for the particular "standard" human organ in question. The standard measurement protocol includes information regarding, for example, the position of the imaging area in the dataset and the position of the imaging area regarding the "standard" human organ. The standard measurement protocol also includes information as to the number of slices, the orientation of the slices, the number of pixels per slice, the size of the pixels, etc. in the imaging area. The standard measurement protocol may allow the measurement of a series of imaging areas and/or may contain information regarding saturation areas, etc.

Such standard measurement protocols can be respectively generated for different types of scans, for example, for a brain scan, a scan of the pituitary gland, and fMRI scan, a scan for epilepsy, a scan of the optical nerves, or a scan of the acoustic nerves.

To be able to use the standard measurement protocol to examine (scan) an individual patient, the protocol has to be adjusted or modified to produce a patient-specific measurement protocol. For this purpose, the organ of the patient for which an image is to be obtained is localized in the data acquisition system (scanner) by a first low-resolution measurement, such as using a 3D localizer or auto align

sequence, and a geometrical mapping of the organ is then undertaken. For this mapping the geometrical relation of the standard (statistical) organ to the organ of the patient must be determined. This can be accomplished by comparing templates, or by a correlation of the corresponding datasets. As a result, a transformation matrix is developed, that defines how to rotate, translate, expand or shrink the image of the patient organ so as to map it with the standard organ. The position of the imaging area (slicebox) of the standard measurement protocol is adjusted according to the transformation matrix. This results in the patient-specific measurement protocol.

A significant advantage of the inventive method is the high degree of reproducibility that can be obtained in the examination. Because the imaging area is each time automatically determined by starting from the standard image area, that is adjusted according to the actual anatomical features of the patient (that in general do not change), the same patient can be scanned a number of times, separated by relatively long time durations, so that the respective images from the time-separated scans can be compared in a meaningful manner. This is particularly advantageous when the scans are for the purpose of following up treatment for a particular pathological condition, such as monitoring the size of a cancerous tumor during the course of radiation therapy or chemotherapy. When a patient is scanned at times that are separated from each other, it sometimes can be difficult to compare the images obtained from the respective scans because it cannot be reliably determined that changes in the images detected as a result of the comparison have occurred because of an actual change in the size of the tumor, or because the orientation of the slice in one of the images was not identical to the orientation of the slice in the other of the images. Because of the high degree of reproducibility achieved with the

inventive procedure, when changes are detected between time-separated images, it can be more reliably assumed that those changes represent actual anatomical changes, rather than changes resulting from inconsistent slice positioning.

A further advantage obtained with the inventive method is a higher patient throughput with regard to the imaging installation, achieved by the significant decrease in time for planning each tomographic measurement.

Although the inventive method has been described above, and is described in more detail below, in the context of magnetic resonance imaging, the inventive method can be used in any type of tomographic imaging modality, including computed tomography and ultrasound, for example.

DESCRIPTION OF THE DRAWINGS

Figure 1 is schematic block diagram of a magnetic resonance imaging apparatus, used an exemplary tomographic imaging modality for explaining the inventive method.

Figure 2 is a flowchart of the basic steps for generating a standard measurement protocol in accordance with the invention.

Figure 3 illustrates the basic components or content of the standard measurement protocol in accordance with the invention.

Figure 4 illustrates the positioning of the slicebox relative to a standard head in a standard measurement protocol produced in accordance with the invention for a brain scan (brain standard).

Figure 5 illustrates the positioning of the slicebox relative to a standard head in a standard measurement protocol produced in accordance with the invention for a pituitary gland scan (pituitary standard).

Figure 6 illustrates the positioning of the slicebox relative to a standard head in a standard measurement protocol produced in accordance with the invention for a fMRI scan (fMRI standard).

Figure 7 illustrates the positioning of the slicebox relative to a standard head in a standard measurement protocol produced in accordance with the invention for a epilepsy scan (epilepsy standard).

Figure 8 illustrates the positioning of the slicebox relative to a standard head in a standard measurement protocol produced in accordance with the invention for a optic nerve scan (optic nerve standard).

Figure 9 illustrates the positioning of the slicebox relative to a standard head in a standard measurement protocol produced in accordance with the invention for a acoustic nerve scan (acoustic nerve standard).

Figure 10 is a flowchart of the inventive method for producing a patient-specific measurement protocol.

Figures 11A, 11B and 11C are exemplary illustrations for explaining the inventive method of Figure 10.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 schematically illustrates a magnetic resonance imaging (tomography) apparatus for generating a magnetic resonance image of a subject, as an example of a tomographic imaging modality operable according to the present invention. The components of the nuclear magnetic resonance tomography apparatus correspond to those of a conventional tomography apparatus, but it is controlled according to the invention. A basic field magnet 1 generates a time-constant, intense magnetic field for polarization (alignment) of the nuclear spins in the examination region of a subject such as, for example, a part of a human body to be examined. The high

homogeneity of the basic magnetic field required for the nuclear magnetic resonance measurement is defined in a spherical measurement volume M in which the part of the human body to be examined is introduced. For supporting the homogeneity demands and, in particular, for eliminating time-invariable influences, shim plates of ferromagnetic material are attached at suitable locations. Time-variable influences are eliminated by shim coils 2 that are driven by a shim power supply 15.

A cylindrical gradient coil system 3 is built into the basic field magnet 1, the system 3 being composed of three sub-windings. Each sub-winding is supplied with current by an amplifier 14 for generating a linear gradient field in the respective directions of a Cartesian coordinate system. The first sub-winding of the gradient field system 3 generates a gradient G_x in the x-direction, the second sub-winding generates a gradient G_y in the y-direction, and the third sub-winding generates a gradient G_z in the z-direction. Each amplifier 14 has a digital-to-analog converter DAC that is driven by a sequence control 18 for the time-controlled generation of gradient pulses.

A radio-frequency antenna 4 is situated within the gradient field system 3. The antenna 4 converts the radio-frequency pulses emitted by a radio-frequency power amplifier into an alternating magnetic field for exciting the nuclei and aligning the nuclear spins of the subject under examination, or of a region of the subject under examination. The radio-frequency antenna 4 is composed of one or more RF transmission coils and a number of RF reception coils in the form of an arrangement (preferably linear) of component coils. The alternating field proceeding from the precessing nuclear spins, i.e. the nuclear spin echo signals produced as a rule by a pulse sequence composed of one or more radio-frequency pulses and one or more gradient pulses, is also converted into a voltage by the RF reception coils of the

radio-frequency antenna 4, this voltage being supplied via an amplifier 7 to a radio-frequency reception channel 8 of a radio-frequency system 22. The radio-frequency system 22 also has a transmission channel 9 wherein the radio-frequency pulses are generated for exciting magnetic nuclear resonance. The respective radio-frequency pulses are digitally presented as a sequence of complex numbers on the basis of a pulse sequence in the sequence control 18 prescribed by the system computer 20. This number sequence - as a real part and an imaginary part - is supplied via respective inputs 12 to a digital-to-analog converter DAC in the radio-frequency system 22 and is supplied from there to a transmission channel 9. In the transmission channel 9, the pulse sequences are modulated onto a radio-frequency carrier signal having a basic frequency corresponding to the resonant frequency of the nuclear spins in the measurement volume.

The switching from transmission mode to reception mode ensues via a transmission/reception diplexer 6. The RF transmission coil of the radio-frequency antenna 4 radiates the radio-frequency pulses, based on signals from a radio-frequency power amplifier 16, for excitation of the nuclear spins into the measurement volume M and samples the resulting echo signals via the RF reception coils. The acquired nuclear magnetic resonance signals are phase-sensitively demodulated in the reception channel 8 of the radio-frequency system 22 and are converted via respective analog-to-digital converters ADC into the real part and the imaginary part of the measured signal, which are respectively supplied to outputs 11. An image computer 17 reconstructs an image from the measured data acquired in this way. Administration of the measured data, the image data and the control programs ensues via the system computer 20. On the basis of control programs, the sequence control 18 monitors the generation of the respectively desired pulse

sequences and the corresponding sampling of k-space. In particular, the sequence control 18 controls the tined switching of the gradients, the emission of the radio-frequency pulses with defined phase and amplitude, as well as the reception of the nuclear magnetic resonance signals. The timing signals for the radio-frequency system 22 and the sequence control 18 is made available by a synthesizer 19. The selection of corresponding control programs for generating a nuclear magnetic resonance image as well as the presentation of the generated nuclear magnetic resonance image ensues via a terminal 21 that has a keyboard as well as one or more picture screens.

The inventive method can be executed using the terminal 21 and the system computer 20. For executing the method illustrated in the flowchart of Figure 2, the system computer 20 can either have stored therein, or have access to, an atlas of anatomical organs. A number of such atlases are commercially available and/or accessible on-line. Such an atlas contains a statistical dataset for each of a number of different anatomical organs.

For the purpose of planning a scan, the atlas or statistical dataset of the organ which will be imaged in the scan is loaded, accessed or retrieved and the particular field of interest in the scan is designated. The imaging area is then designed, and the relevant parameters that have been entered are stored together with a reference to the atlas that was employed in producing this standard measurement protocol.

The basic contents of the standard measurement protocol for each type of scan that is developed according to the flowchart shown in Figure 2 are presented in Figure 3. These components include the pulse sequence that will be used in the scan, the coordinates of the imaging area, and a reference to the atlas that was used in producing the protocol.

The region in which the slice or slices in the scan will be obtained is known as the "slicebox." The orientation of the slicebox for a number of different standard measurement protocols produced in accordance with the invention are shown with reference to a standard head in Figures 4 through 9.

Figure 4 illustrates the orientation of the slicebox relative to the standard head (head atlas) for a brain scan (brain standard). Figure 5 shows the orientation of the slicebox for a scan of the pituitary gland (pituitary standard). Figure 6 shows the orientation of the slicebox for functional magnetic resonance imaging (fMRI standard). In a functional magnetic resonance imaging scan, the subject is periodically stimulated, such as by a flashing light, and brain activity is detected by monitoring the increased oxygen consumption that occurs in the portion of the brain wherein activity is caused by the stimulation.

Figure 7 illustrates the orientation of the slicebox relative to the standard head for a scan to detect symptoms in the brain indicative of epilepsy (epilepsy standard). Figure 8 illustrates the orientation of the slicebox (here, as in Figure 5, a single slice) for a scan of the optic nerves (optic nerve standard) and Figure 9 illustrates the slicebox for a scan of the auditory nerves (auditory nerve standard).

The production of such standard measurement protocols for different organs in accordance with the invention has "stand alone" utility, and can be used for other purposes. Further in accordance with the present invention, however, the standard measurement protocol is used in the method illustrated in Figure 10 for producing a patient-specific measurement protocol. As illustrated in Figure 10, a patient dataset is created with an auto align sequence, which represents the actual position of the patient in the scanner for a particular examination. The patient dataset is statistically analyzed, and the appropriate standard measurement protocol, for among the

standard measurement protocols generated as described above, is selected. The statistical dataset (atlas) that is referenced in the selected standard measurement protocol is then loaded (or accessed or retrieved). A transformation matrix is then calculated which provides a mapping between the statistical dataset and the patient dataset. The standard measurement protocol is then transformed or converted, using the transformation matrix, to a patient-specific measurement protocol for the particular patient and the particular scan.

The procedure set forth in the flowchart of Figure 10 is illustrated in the sequence shown in Figures 11A, 11B and 11C. The illustrations that are schematically shown in Figures 11A, 11B and 11C may be visually displayed at the screen of the terminal 21, if desired, however, since it is not critical for the operator to actually view these representations, Figures 11A, 11B and 11C can be considered as schematic illustrations of the data manipulations that are taking place in the computer during the execution of the inventive method.

Figure 11A shows a standard head (head atlas) in three different views with the standard measurement protocol (SMP) slicebox indicated relative to the standard head. This representation can correspond to any of the examples shown in Figures 4 through 9, or a standard measurement protocol for some other organ.

Figure 11B shows the same views of the head, but these views are obtained from the low-resolution scan of the actual patient in the scanning apparatus. The orientation of the organ of interest, in this case the patient head, will almost certainly be different from the orientation of the standard head shown in Figure 11A. The SMP slicebox, however, is shown in each view in a position that is identical to the slice box position in Figure 11A. Since the actual position of the patient head is

different from the position of the standard head, the SMP slicebox would not be properly oriented relative to the actual patient head for conducting the desired scan.

In order to restore the proper orientation between the patient head and the slicebox, the aforementioned transformation matrix is generated, which represents a mapping between the standard head and the patient head. The data representing the SMP slicebox in Figure 11B are then operated on by the transformation matrix, thereby producing a transformed slicebox shown in Figure 11C. This transformed slicebox has the same orientation relative to the patient head as the SMP slicebox has relative to the standard head.

Figure 11C therefore represents the resulting patient specific measurement protocol at the end of the flowchart in Figure 10. The actual diagnostic scan can then be conducted using this patient-specific measurement protocol.

As noted above, although the inventive procedure has been explained in the context of magnetic resonance imaging, it can be used with similar benefit in other types of tomographic imaging, such as computed tomography and ultrasound.

Although modifications and changes may be suggested by those skilled in the art, it is the intention of the inventors to embody within the patent warranted hereon all changes and modifications as reasonably and properly come within the scope of their contribution to the art.